Shallow Water Acoustic Experiment Analysis

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LONG-TERM GOALS

The long-term goal of the research is to increase the physical understanding of acoustic propagation in shallow water ocean environments in the 25-5000 Hz band. This includes both the physics of the seabed and the coupling of physical mechanisms in the water column and the seabed in complex range- and azimuth-dependent littoral waveguides.

OBJECTIVES

The main objective of the current research is to use inferences of ocean waveguide parameters combined with geophysical data from the Shallow Water 2006 (SW06) experiment to model range-dependent acoustic data for the purpose of determining the effects of range-dependent inhomogenities.

APPROACH

Acoustic measurements on the New Jersey continental shelf were made over propagation paths where previous geophysical analyses provide information on the seabed layering structure.[1] Additional information on the physical properties of the sediment layers, such as sound speed and attenuation, were obtained from data segments along a short-range propagation path that exhibited a small degree of inhomogeneity.[1] The seismic and the geophysical information[2-5], the inferred geoacoustic information for the sediment layers, and sparse water column sound speed measurements provide inputs for a finite element parabolic equation model.[6] With this information modeled time series can be constructed for comparison to the received times series in the 35-264 Hz band from an impulsive sound source at ranges between about 70 and 350 water depths.

The interpretation of acoustic propagation in ocean waveguides is required to study physical mechanisms in both the water column and the seabed. Such mechanisms include mode coupling induced by range variability, scattering from rough interfaces, and the relaxation mechanisms

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14. ABSTRACT
The long-term goal of the research is to increase the physical understanding of acoustic propagation in shallow water ocean environments in the 25-5000 Hz band. This includes both the physics of the seabed and the coupling of physical mechanisms in the water column and the seabed in complex range-and azimuth-dependent littoral waveguides.

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responsible for sound speed and attenuation dispersion in marine sediments. Inversion or maximum likelihood methods assist in the inference of waveguide parameters and in the interpretation of the acoustic measurements. However, environmental variability, noise in the data, source-receiver motion and source level variability, and model errors cause uncertainty in the inferences of parameter values. Thus, it is natural that one desires a method to quantify this uncertainty. The approach selected to quantify uncertainty is the maximum entropy (MaxEnt) method.[7-9] The resulting posterior probability distribution is known as the canonical distribution. A parameter called the temperature appears in the canonical distribution and is determined from a constraint placed on the maximization of the Gibbs entropy using information obtained from the properties of a cost function. An importance sampling approach (Metropolis-Hastings) is required to compute the N-1-dimensional integrals for the marginal probability distributions.

WORK COMPLETED

The work completed in FY09 includes the development of a numerical implementation of a methodology to quantify waveguide and source parameter statistics using a MaxEnt approach. The theory is straightforward, however, as with a Bayesian approach, the details of computing the N-1 dimensional integrals for the marginal distributions required an implementation of a Metropolis-Hastings algorithm. The precise definition of uncertainty is still being investigated in part because strong parameter coupling or correlations increase the entropy for correlated parameters. How to define uncertainty in the presence of parameter correlation is not well understood. Preliminary results using the MaxEnt method have been obtained and the inferred geoacoustic structure is consistent with sediment core samples.[4]

Using information provided by inversion of short- and long-range towed CW data, a finite element parabolic equation (PE) model was used to interpret measured low-frequency (35-264 Hz) broadband sound propagation through range-dependent propagation paths. How to connect the uncertainty approach to the full range-dependent problem is currently under investigation.

RESULTS

Figure 1 shows the geographical locations of three acoustical arrays, a track of the RV KNORR as it towed a J-15-1 source that emitted four tonals in the 50-250 Hz band, and the deployment locations of two Combustive Sound Source (CSS) events. The seabed layering structure of the region was previously mapped by chirp bottom reflection measurements from two surveys prior to the acoustic experiment. All three acoustical arrays had vertical and bottom-mounted horizontal components. The track over which the narrowband source was towed starts near Array 2 in the NW direction and passes within about 100 m of Array 1. The source locations of the CSS 26 and CSS 18 events are near the tow track.

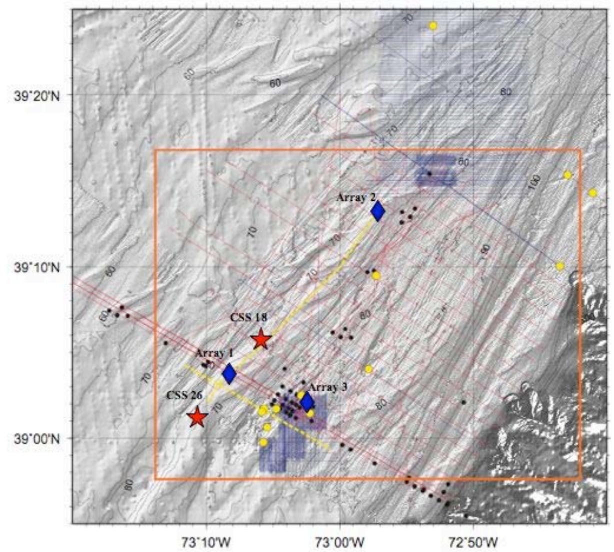

Figure 1: Shallow Water 2006 experimental location and positions of sources and receivers.

Figure 2 shows an example of marginal probability distributions using the MaxEnt approach for source track parameters, the water depth, and selected geoacoustic parameters that are obatined using short range (less than 5 km) tow acoustic data collected on Array 2 in the 50-250 Hz band. The geoacoustic parameter that is best defined is the sound speed ratio at the water sediment interface with a most probable value of about 1.12, corresponding to a surface speed of about 1665 m/s.

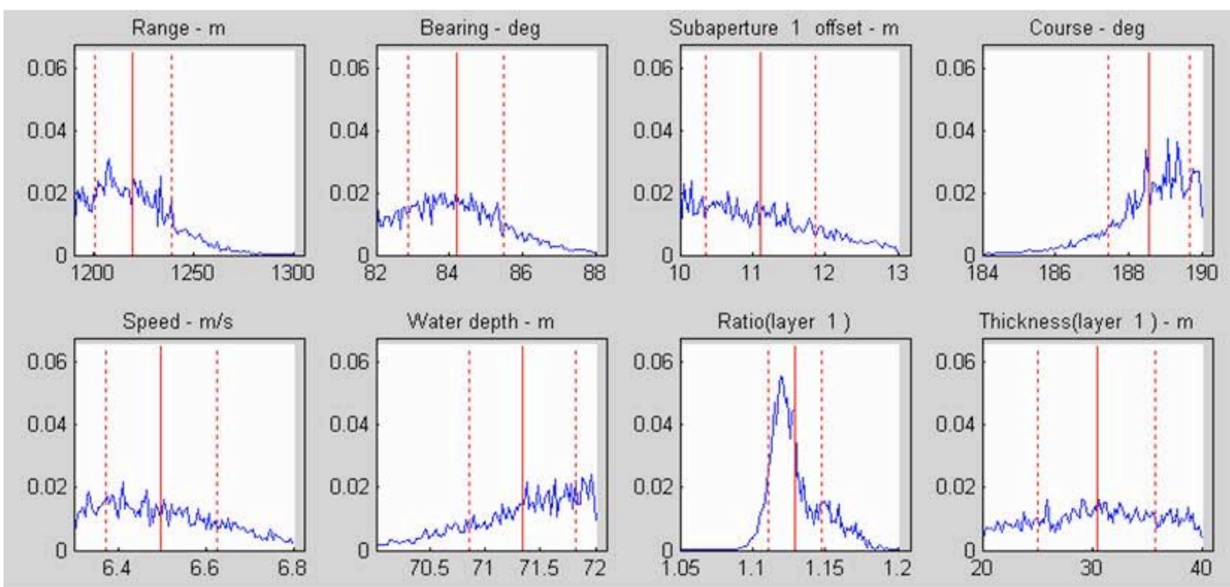

Figure 2: Marginal probability distributions for track and selected geoacoustic parameters dervived from data collected on 52-element L-array using simultaneous processing of vertical and horizontal components.

Figure 3 shows subbottom layering as a function of range along propagation tracks examined in this study. The layering structure was interpolated from seismic horizons interpreted from previously-collected chirp reflection data.[2-5] Figure 3a shows the subbottom layering structure and bathymetry along the tow track. Figure 3b shows the subbottom layering structure and bathymetry between Array 3 and the CSS 26 source location. The water depth at Array 1 is about 70 m, and about 3 m variations in the water depth are observed between Array 1 and Array 2. The water depth at Array 3 is about 80 m. As observed in Fig. 3b, the water depth between Array 3 and CSS 26 varies from about 70 to 92 m.

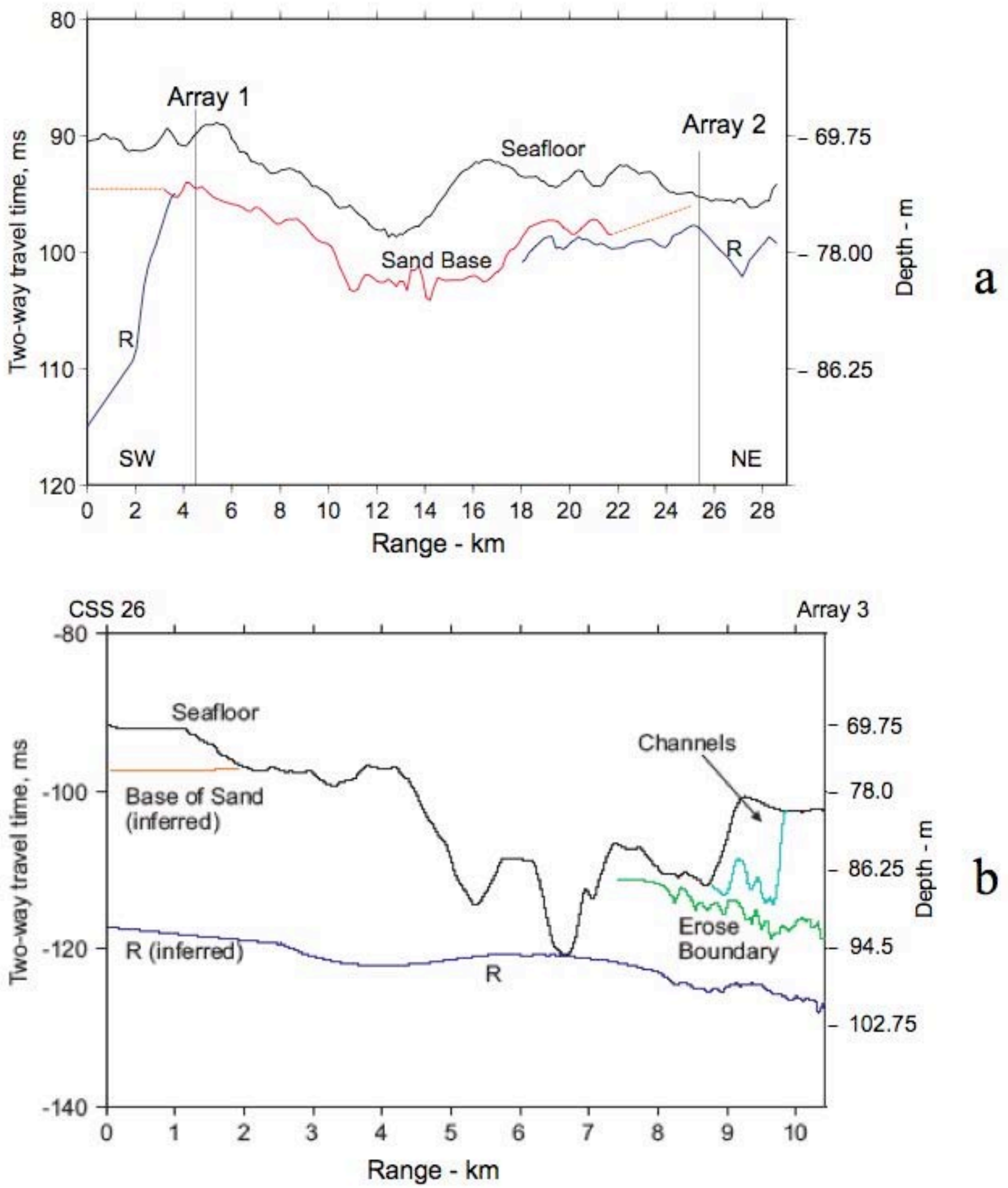

Figure 3: Measured seabed layering in SW06 experimental area.

Transmission loss (TL) was simulated as a function of range and frequency for each receiver depth of the vertical segment of Array 2. Fifteen hydrophones populated the water column in 4.37 m increments starting at 11 m down to 72.14 m. In this calculation and calculations that follow, only a course sampling of range dependence of the environment (SSP, seabed, and bathymetry) was input into the PE model. Figure 4 is a comparison of measured and modeled TL over a range scale of about 24.5 km. The modeled and measured TL levels at 53 Hz show a bimodal pattern, as they do at 103 Hz except the contribution from at least one other mode is evident in the interference pattern. As the frequency increases the presence of higher order modes becomes increasingly evident and the interference structure persists over the entire 25 km range interval. It is of interest to note that as the frequency increases one observes higher loss near the surface. One may ascribe this observation to the fact that the higher order modes, which penetrate the thermocline and are thus present near the surface, have increased modal attenuation coefficients as compared to the lower order modes that have small amplitudes near the surface.

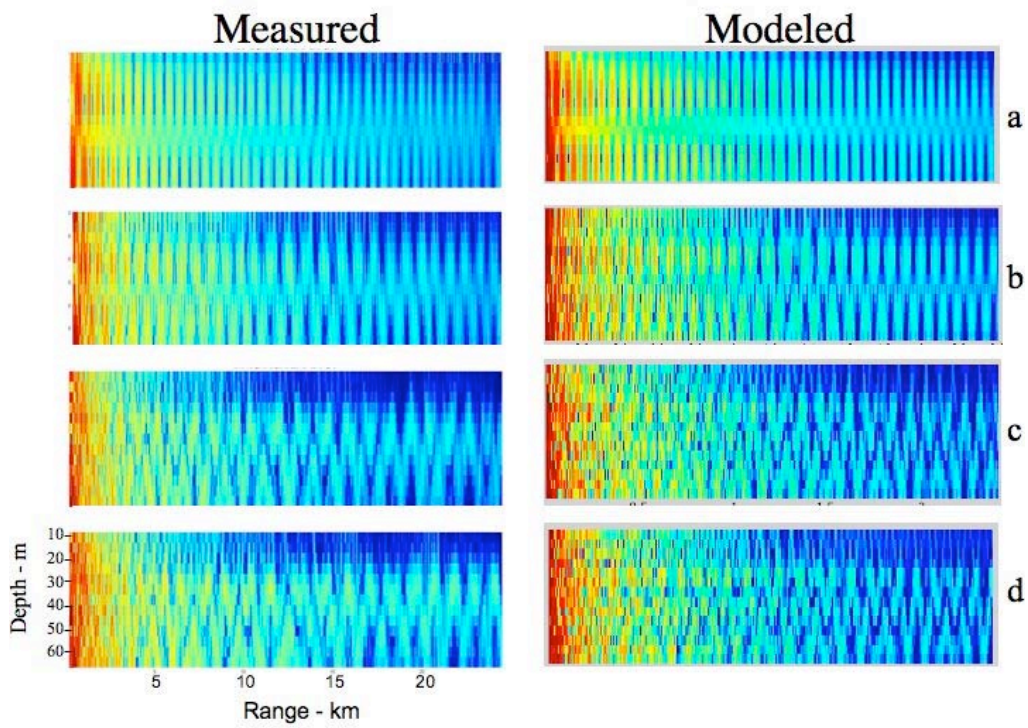

Figure 4. Model-Data comparisons of TL at (a) 53 Hz, (b) 103 Hz, (c) 203 Hz, and (d) 253 Hz in range depth plane at Array 2.

While the simulated and the measured TL are in fair agreement, there are differences worth noting. The measured TL values appear to be *smoother* at the higher frequencies as compared to the modeled results. The modeled results assume uniform motion. It was observed that during the tow experiment the source depth underwent small fluctuations on the order of 1m. It is conjectured that this would have a *smoothing* effect as observed for the higher frequencies because for a specific depth the range interference pattern becomes increasingly sensitive to source depth.

Figure 5 shows the model-data comparisons of the received time series in the 35-264.35 Hz band from the CSS event 26 on Array 1 at three receiver depths and Fig. 6 is a comparison of the model and data time series from the CSS event 26 on Array 2 at a receiver depth of 71 m. To

eliminate the effects of two interferers at Array 2 on azimuths different from the source at broadside, the signals on the horizontal segment of Array 2 were adaptively beamformed. Overall, the simulated results are in fair agreement with the measured time series. The details of the coherent arrival structure is sensitive to a number of factors, including the sound speed of the top sediment layer (in this case about 1650 m/s). The observation that the coherent structure of the simulated time series agrees with the measured structure is consistent with the observation that the coherent structure (interference patterns in the range-depth plane) of the simulated TL agrees with the measured TL. That the received pulse length of the simulated and measured time series agree is an independent confirmation that the attenuation values deduced in Ref. 1 are approximately correct.

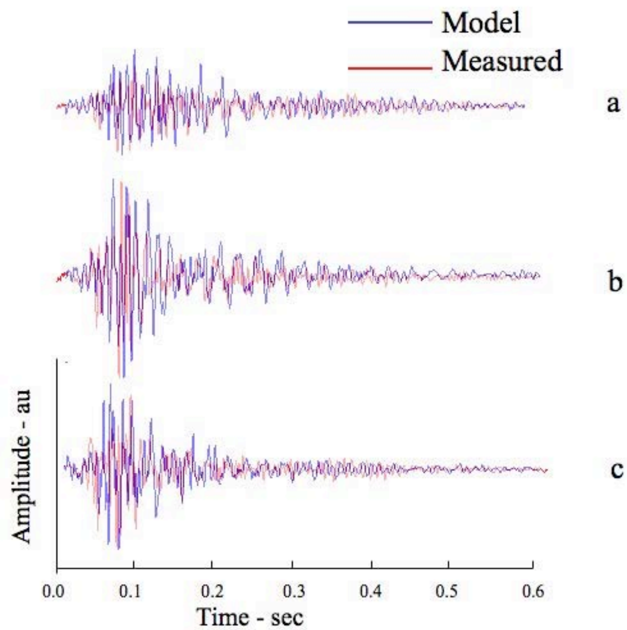

Figure 5: Model Data comparisons of CSS Event 26 at Array 1 in 35-264.35 Hz band, Range = 4.86 km, Source Depth = 26.3 m (a) Receiver Depth = 9.935 m, (b) Receiver Depth = 27.795 m, (c) Receiver Depth = 51.615 m.

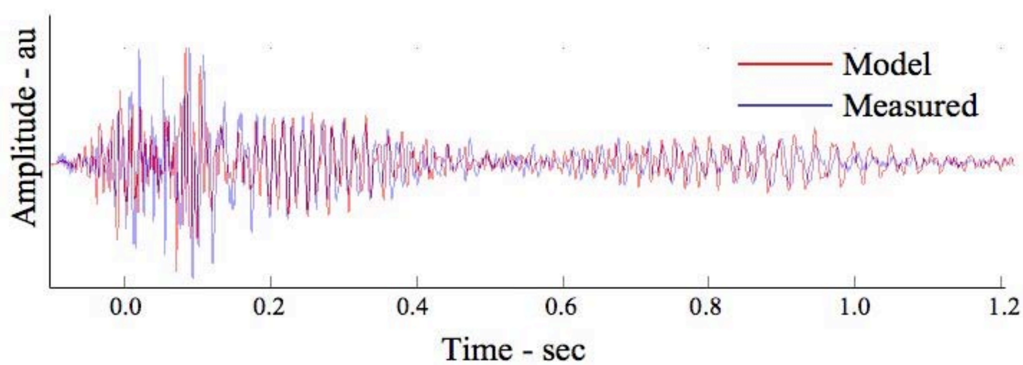

Figure 6: Model-data comparison for CSS Event 26 at Array 2 in 35-264.35 Hz band. Range = 26.3 km, Source Depth = 26.3 m, Receiver Depth = 71 m.

Figure 7 shows the model-data comparisons of time series in the 50-264 Hz band at Array 3 from CSS Event 26 at four receiver depths. The lowest frequency of 50 Hz was selected for the

comparisons because the measured data were contaminated with noise in the 35-45 Hz band. The modeled and measured time series are presented such that the first arrivals are aligned. Overall the simulated and measured time series are in good agreement; however past the first 75 ms, the measured and modeled arrivals are slightly out of phase. Even though the bathymetry and range-dependent layering were approximately accounted for in the simulation, the comparisons of the measured and modeled time series are not as good as those observed for the received time series on Array 1 and Array 2. Sensitivity studies with source depth, receiver depths, bathymetry, and sediment sound speeds demonstrated that this phase mismatch could likely be ascribed to an incorrect representation of the range dependence of the SSP; specifically, there exist unknown range-variations that act to decrease the group velocities of higher order modes relative to mode 1.

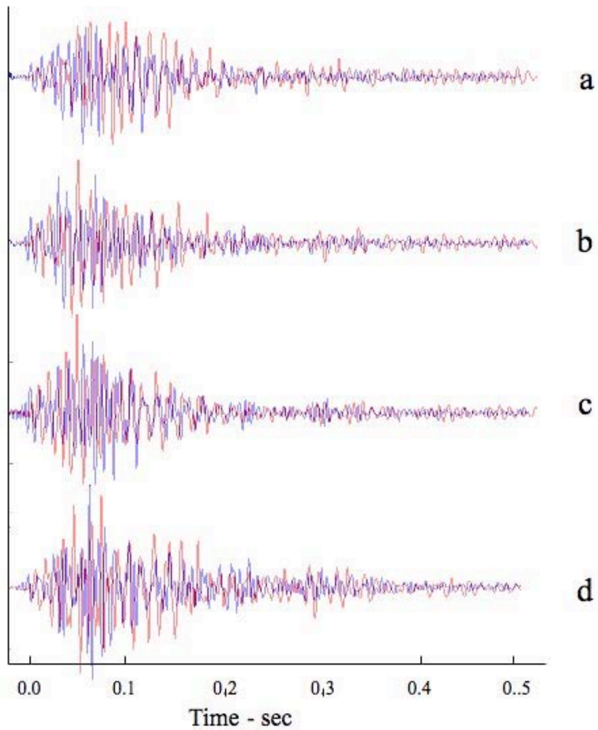

Figure 7: Model-data comparison for CSS Event 26 at Array 3 in 50-264.35 Hz band. Range = 10.43 km, Source Depth = 26.3 m, (a) Receiver Depth = 24.75 m, (b) Receiver Depth = 39.75 m, (c) Receiver Depth = 62.25 m, and (d) Receiver Depth = 77.25. Modeled time series is the red curve and measured time series is the blue curve.

The results of the study suggest that the coherent structure of low frequency long-range propagation in an area known for its environmental complexity can be *reasonably* simulated with a coarse sampling of environmental parameters such as the sound speed profile, the bathymetry, and the geoacoustic profile. However, the above is only an initial analysis of the range-dependent acoustic data. Advances will need to be made in the implimentation of a range-dependent inversion and uncertainty analysis before any significant conclusions can be made concering the effects of the range-inhomogenities on sound propagation.

IMPACT/APPLICATIONS

One potential impact of this research is that these studies may assist in understanding how to optimally combine advance propagation models (non-separable and 3-D) and information inference methods as one proceeds to study ocean waveguides with increasing complexity and inhomogeneity.

TRANSITIONS

Transitions of this research may include inversion model development that gives mean and standard deviations for selected environmental and sonar parameter values.

RELATED PROJECTS

Related research projects include modeling reverberation in range and azimuth dependent littoral areas, ambient noise analyses in both deep and shallow water environments, and calculations of environmental uncertainty for acoustic data collected in experiments other than SW06.

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HONORS/AWARDS/PRIZES

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